CONFERENCIA

Climate and the Amazon

Clima en el Amazonas

PETER BUNYARD[1]
[1]Biólogo, PhD. Boston University, USA
Recibido: 18 Mayo de 2007; Aceptado: 15 junio de 2007.

When concerning ourselves with the future of the earth's climate we must not make the grave mistake of counting only the quantities of carbon dioxide released into the atmosphere from the combustion of fossil fuels, while neglecting those from changes in vegetation cover. But, there is another crucial dimension too: the role of natural ecosystems in giving us a climate we can live with. In this context the future of the Amazon forest is absolutely vital.

In its entirety the Amazon Basin covers some 7 million square kilometres, the lion's share, some 5 million square kilometres in Brazil, and the remainder across seven independent nations plus France's colony Cayenne. At least 60 per cent of the world's remaining tropical rainforests, with their unsurpassed biodiversity, including an estimated 55,000 different plant species, are to be found in the Amazon. Moreover, the forests in the Amazon Basin contain at least one-fifth the equivalent of all the carbon currently in the atmosphere and recent studies suggest that intact Amazonian forests may also be functioning as a globally significant carbon sink, mopping up some of the carbon dioxide released into the atmosphere from industrial emissions.

On the other side of the coin, any 'extra' uptake of carbon by the intact forest is more than outweighed by carbon emissions from deforestation. For many years, Philip Fearnside, of the National Institute of Amazonian Research (INPA) in Manaus, has carefully amassed information about Brazil's Legal Amazon. His research indicates that by 1998, the area of forest cleared in the Brazilian Amazon had reached some 549,000 square kilometres, about the size of France out of a total area as large as Western Europe. In a few decades, Brazil has managed to deforest an area far greater than that lost over the preceding five centuries of European colonization.

Moreover, the destruction has continued. In 2003 some 23,750 square kilometres, an area the size of Belgium was cleared, two per cent up on 2002. In 2004, remote satellite sensing picked up more than 35,000 separate fires in the Brazilian Amazon and the situation was only marginally better in 2005.

Conservation bodies, such as WWF and Conservation International, have understandably focused on the need to protect regions within the Basin that are known to be rich in biodiversity. The hope is that a network of such regions, linked by ecological corridors, would guarantee the survival of as much as 80 per cent of biodiversity. But such conservation practices are likely to fail unless a wider conservation strategy is adopted which takes account of the hydrological cycles of the region. The integrity of the forests of the Eastern Amazon safeguards that of the forests in the West. Even forest reserves of a million hectares or more may deteriorate rapidly if the hydrological process is disrupted because of deforestation in bordering regions.

Texto. Conferencia presentada en la Primera Jornada de Investigación -Unillanos 2007-.

The healthy forest not only assures the circulation of moisture, it also accumulates carbon from the atmosphere in the form or organic matter and biomass. According to John Grace, of Edinburgh University and others, who have been contributing to the Large-scale Biosphere-Atmosphere Program (LBA) Experiment in Amazonia, the average uptake of carbon dioxide over the entire basin in non El Niño years may be as much as 0.56 GtC per year (109 tonnes of carbon per year), hence equivalent to eight per cent of total annual emissions from all human activities. Just on their carbon uptake alone, says Grace, such rainforests provide an irreplaceable global environmental service.

Carbon releases

The downside is the release of carbon from deforestation. Fearnside estimates such carbon emissions, which take account both of decay following large-scale forest fires and of any future reabsorption of carbon by the new, modified landscape. During the1980s the average annual emissions from deliberate land-use change in Brazil was 0.556 billion tonnes of carbon, or about one-eleventh of the 6.4 GtC (gigatonnes of carbon) emissions from fossil fuel burning across the planet, and just under one-quarter of the total 2.4 GtC emissions from the tropics. Indeed, deforestation in the Brazilian Amazon makes the country's per capita emissions of carbon as high as those of Briton or Germany.

Optimistic statements - that whatever vegetation replaces the forest, such as pasture, it will eventually regain all the carbon that has been lost - have proved to be wishful thinking: field research indicates that at most seven per cent of the original carbon gets reabsorbed over time by the replacement landscape. Another mistake is to ignore the carbon release from the decomposition and decay of the remaining biomass after the initial burn. According to Fearnside, the final tally of carbon emitted from burning felled trees is likely to be at least three times greater than measured at the time of the fire. As a result, the emissions in any one year may be augmented by emissions from deforestation that took place in a previous year.

Were all the remaining Brazilian Amazon forests to be lost, then, according to Fearnside, the potential emissions would amount to as much as 77 GtC, a quantity that conforms to the predictions by Richard Betts at the UK Meteorological Office. That amount would be 10 per cent higher than the 70 GtC that could be gained from the full implementation of the Kyoto Protocol together with a one per cent compounded reduction per year in the emissions of developed countries from fossil fuel burning between 2010 and 2100.

Timber extraction

Meanwhile, logging across the Amazon is accelerating. Multinational timber companies, particularly from Malaysia and Indonesia, have entered the Amazon in a big way. In 1996 alone Asian companies invested more than US$500 million in the Brazilian timber industry. They now own or control about 4.5 million hectares of the Brazilian Amazon, according to Brazil's national environment agency, IBAMA. In 1997 Greenpeace International investigated the Brazilian trade in mahogany and discovered that at least 80 per cent was illegally harvested, much of it destined for Japan. The government accepted Greenpeace's findings, and in order to combat the poor forestry practices that go with illegal extraction, it announced that it would open an additional 14 million hectares of forest in 39 national forests to *bona fide* timber companies, the rationale being that it would therefore be able better to control and regulate logging practices. Greenpeace estimates that at current rates of logging virtually all the mahogany worth extracting will have been taken in as little as eight years. Recent research indicates that selective logging, even when legal, damages and kills many more trees than the one taken out. For every tree extracted, 30 more trees are damaged and become vulnerable to forest fires.

Avança Brasil

Avança Brasil came into being under Fernando Henrique's government in the 1990s. It was designed to increase trade through the expansion of industrial agriculture and mining in the Brazilian Amazon. But environmental and scientific critics soon expressed concern that the programme would have a devastating impact on the remaining forest areas. In 2001 Bill Laurance, from the Smithsonian Tropical Research Institute in Barro Colorado, Panama, warned that over the next 15 to 20 years *Avança Brasil* could accelerate the processes of degradation to the point where more than 40 per cent of the forest would have vanished. Moreover, the forest areas left standing would be highly fragmented and vulnerable to further encroachment as well as degradation through 'edge effects' involving increased vulnerability to fires and penetrating winds.

The intention of *Avança Brasil* was to pave about 7,500 kilometres of roads, some new and others currently dirt track. Paved roads were then designated as highways, which, as Laurance points out, "greatly affect the ease with which loggers, colonists, ranchers and land-speculators can gain year-round access to forests, and lower considerably the costs of transporting timber and other forest products to urban markets. Moreover, highways in the Amazon frequently lead to the spontaneous generation of entire networks of additional roads. For example, the Belém-Brasilia highway - created in the 1960s - is today surrounded by a 300 to 400 kilometre-wide swathe of state and local roads as well as logging tracks that has led to a drastic rise in deforestation. Similar networks are evident throughout much of the southern and eastern Amazon."

Avança Brasil has now been augmented by new schemes. Following Brazilian president Luiz Inàcio Lula da Silva's visit to Beijing in 2004, and the return visit to Brazil by the Chinese president, Hu Jintao, trade agreements were thrashed out between the two countries whereby, in return for infrastructure investment of some US $10,000 million, particularly in Brazil's Amazon region, China would have access to commodity products, such as timber, iron and soya. The resulting figures speak for themselves: According to government figures, Brazil's exports of goods to China, primarily soya and iron ore, jumped from US $676 million in 1999 to US $5,400 million in 2004, and that rise continues unabated. To accelerate exports from the Amazon, China has signed an accord with Brazil to help develop the infrastructure necessary for the export of Amazon products over the Andes and across the Pacific.

The consequences of that trade with China, as well as with Europe, has been rampant deforestation, particularly in Mato Grosso and Rondônia. Overall soya production in Brazil now takes up more than 20 million hectares (just short of the size of the UK), with the export of 36 million tonnes, and a return of some 8,000 million dollars. In 2004, Mato Grosso, mainly as a result of the initiative of the State governor, Blairo Maggi, the so-called 'King of Soya', had 5 million hectares down to soya, a growth of 12.4 per cent compared to the previous year.

Between August 2002 and 2003, Mato Grosso lost 10,416 km2 of forest, representing 43.8 per cent of the total area deforested in that space of time in the rest of Amazonia and Brazil in general. Add to that the loss of forests in the Cerrado region of Mato Grosso - in all probability greater in area than the loss of humid tropical forests - and we can see that soya production destined for China and Europe has become a major engine of Amazon ecosystem destruction.

Since 1999, the federal government of Brazil has held discussions with State governments to develop a strategy of sustainable development for the Legal Amazon region of Brazil, with the intention of decreasing the rate of deforestation while simultaneously helping local populations in their struggle for economic survival and in that vein has recently established a Brazilian Forest Service. In 2004, the government launched its Deforestation Control and Prevention Plan, and, in addition, ordered that 19 million hectares should be set aside for conservation.

According to Mary Helena Allegretti, a former Coordination Secretary for Amazonia in the Ministry of the Environment, such initiatives may have helped in reducing the annual burn by 30 per cent to an estimated 13,100 km2 between August 2005 and 2006. That estimate was based on reduced satellite data and must be put into perspective against the increase in smoke contamination that reached right up into the Colombian Putumayo and into Colombian Amazonas. The drying-out of forests in the vicinity of tracts of deforestation may well have contributed to the extent of forest-burning during 2005.

And if the burn was down in Mato Grosso, that might have had as much to do with depressed soya prices as to new-found enlightenment about conservation, according to Philip Fearnside at the National Research Institute for Amazonia. He remains concerned at the government's intention to continue with its plans to rebuild the BR-319 which will open up the heart of the Amazon to would-be deforesters and land-grabbers.

Soya - the environmental and social implications

As Philip Fearnside points out, soya growing in Brazil spread initially from the states of Paraná and Rio Grande do Sul in the south, to the *cerrado* (savanna) region in Mato Grosso. Meanwhile, all along the way peasants have been displaced, either those in the south who were living off subsistence maize, beans and coffee, or those who had already cleared land in the *cerrado* and parts of the Amazon, as in Rondônia. Since soya production employs only one person on the ground for every 11 subsistence farmers, the peasants have little choice either to move to the city or to move the colonisation frontier ever onwards and outwards. In 1996, for instance, Rondônia had 1,800 hectares down to soya; in 1998, the area had expanded to 4,700 hectares and one year later to 14,000 hectares. In Maranhâo the soy area increased from 89,100 hectares to 140,000 over the same period.

The advancing front of industrial soybean production is the leading driver of all major new transportation projects, including the creation of new highways, the channelisation of rivers for navigation, and the construction of new railroads, which will penetrate from the centre of Brazil into the heart of the Amazon. What is therefore no less than a massive government subsidy is intended to get cheap soya transported by ship to Europe, and particularly to Holland for fattening pigs and milk production, and to China, where much of the imported soya is pressed for oil.

But the destruction of rainforest is not just limited to soybean production and the need to get the soya exported out of the country. The very penetration of the Amazon leads to other 'dragging effects' in which more forest is cleared for cattle ranching and for illegal timber extraction than would otherwise occur. Meanwhile, a Dutch agribusiness company is talking of establishing industrial-scale pig farming in Mato Grosso, based on feeding them on local soya. There has also been talk of shipping pig manure from the Netherlands back to Brazil in the same boats that are now used for exporting soya from there.

Between 1970 and 1996, the GNP in Brazil's Legal Amazonia, jumped from US$8.5 billion to $53.5 billion, while the population in the region increased from 7.7 million to 18.7 million, a six-fold increase in 'wealth' compared with a 2.4 fold increase in population; but at what cost? In terms of indices of 'human development', all the Amazonian states had a much poorer showing than was found in the rest of the country, with a large proportion of the local population earning less than the minimal wage. All that can mean only one thing: the wealth generated in Brazil's Amazonia had mostly been exported at the expense of the environment and people.

The 'development' of the Amazon is also closely associated with hydroelectric schemes. Projects such as the Tucuruí and Balbina dams have come under heavy criticism for their failure to meet with expectations and their disastrous impacts on their surroundings. Balbina, for instance, despite causing the flooding and destruction of around 3,000 square kilometres of forest, is incapable of meeting the electricity needs of the nearby city of Manaus. Far from being benign sources of energy with regard to emissions, such hydroelectric plants bring about the release over their lifetimes of at least as much greenhouse gases as from a coal-fired plant generating the same amount of electricity, mainly in the form of methane gas.

A year without precedence

Over the Amazon Basin, 2005 was a year without precedence. Never before in recorded history had the region, especially in Brazil, suffered such an extensive and devastating drought, not even in the years of strong El Niño events, when the Tropical Pacific Currents switch and the trade winds, skimming over the surface from Africa to South America, falter and die away. 2005 should have been a normal, non-El Niño year, with strong trade winds picking up enormous volumes of water vapour from a warm tropical ocean, and dumping their load over the humid tropical Amazonian forests of Brazil.

But that is not what happened. Instead, the weather systems of the North Atlantic had transformed dramatically, with the Azores, normally a region of high pressure and sinking air, becoming a region of low pressure, with warm, moist air convecting upwards. Such a turn-around could explain in part why southwest Spain had its first ever tropical storm; why the hurricane track hit further south than normal, striking well within the Gulf of Mexico and destroying New Orleans in the bargain; it could also explain why the Caribbean coast of Colombia was subjected to unprecedented rains in November, causing widespread flooding and deaths; and, above all else, why the central and western Amazon Basin was left high and dry.

During the Amazonian drought, river levels fell to their lowest ever, and Brazilian authorities declared four municipalities 'disaster areas' and another 14 in a 'state of alert'. A heavy layer of cold, dry air had formed close to the ground, encompassing hundreds of thousands of square kilometres, reaching right up into the Colombian Putumayo, and effectively preventing the convection process that leads to thunderstorms and rain. Held down by that layer, the smoke from more than 30,000 forest-clearance fires in Brazil had nowhere to go, except to make life extremely uncomfortable for people in Brazil, Peru and Colombia, who had to put up with a burning throat and smarting eyes for days on end. Aircraft were unable to land in

Leticia and Tabatinga, the latter just across the border from Colombia and, when the smog was at its thickest, no-one dared make the crossing to the other side of the Amazon River for fear of colliding with a floating log, or worse still another boat.

Was climate change to blame? Certainly sea surface temperatures across the Caribbean were at their highest recorded, not just spawning more hurricanes than ever before, but leaving coral reefs bleached of their algae and dying. The loss of the reefs, the loss of mangrove swamps, all led to the coastline becoming ever more vulnerable to sea level rise and storm surges.

But, what about deforestation across the Latin American tropics and in particular across the Amazon Basin? Could deforestation, with resulting alterations in the transport of latent heat in the form of water vapour out of the tropics have played a role? We do not know for certain, but we are being made increasingly aware that even small changes in heat transfer from the equator to the high latitudes can have a profound effect on weather systems. What should worry us is whether the changes that occurred in 2005 across the tropical Atlantic could become a regular feature. Were that to be the case, then we could see the demise of the great tropical rainforests across the Amazon Basin.

Already, we are seeing parts of the Basin drying out and forming savanna, with its mixture of drought tolerant shrubs and grasses, in what may well be the beginnings of savannization, a process that could lead to desertification. That change indicates that the natural watering system over South America is breaking down; large forest areas are no longer able to sustain themselves. And without the forests, all the countries in South America would suffer dramatic changes to their climate and rainfall. The consequences would be catastrophic and much of the rest of the planet would be affected by such changes.

Ecosystems and Climate

Climatologists have for the most part ignored the dynamics of life's interactions with climate, aside from human-induced increases in greenhouse gases. And by ignoring 'life' in their models, climatologists have generated half-baked models. The problem climatologists face is to encompass all the prime factors that make up climate and then somehow transform those same factors into heat budgets that drive mass circulation systems, including the Hadley Cell circulation of the tropics and ocean currents such as the Gulf Stream. The heat budget is also affected by the evaporation of water and by alterations in the Earth's albedo – the reflectivity of the Earth's surface – as a result of variations in cloud, snow, ice cover and precipitation patterns.

By no means an easy task, and, aside from the question raised about the intervention of life in the formation of climate, big questions remain over the validity of the predictions of the GCMs — the general circulation models. To get a grip on climate change we have to show just how much the fluctuations in climate from year to year and changes in surface temperature are the result of natural variability, all within an extremely complex system that has non-linear equations and chaos writ large as part of its defining principles.

In that regard, Makarieva and Gorshkov from St Petersburg are transforming our thinking about the critical importance of maintaining natural forest cover over large continents. Without inland forests to pump water vapour back into the atmosphere, the water vapour picked up from the ocean and deposited as rain will decline exponentially as the air currents move inland. The natural, broad-leafed, forest carries out transpiration through the stomata of their leaves at a rate that compensates absolutely for the exponential decline in rainfall and so maintains soil moisture and rates of evapotranspiration in a self-feeding, highly selected system. Alternative vegetation cannot do the job and, if inland natural forests are replaced by agro-industrial enterprises on a sufficiently large scale, the consequences must be a drying out of the entire system. According to the Russian scientists, the Hadley Cell airflow over the tropics depends essentially on the forests to provide the necessary convective gradient. Hence, a swathe of forest destruction up to several hundred kilometers from the Atlantic Ocean could put paid to the forests further inland and lead to dramatic changes in the Hadley Circulation. The net result would be spreading-desertification as happened in Australia in a process that occurred over thousands of years of human invasion and settlement.

Climatologists have long agreed on the notion of a 30-year moving averaging out of annual data so as to avoid statistical errors in ascribing climate change to what may be a 'one-off' result. However, that leads to a possible risk of underestimating *bona fide* changes by blurring them with the statistical weight of previous years, so that we may get wise to climate change only when we are well and truly in the midst of it, and therefore too late to act in time. For instance, much of the 0.7o C temperature rise seen over the past century occurred during the last decades of the century. Certainly alarm bells should ring that we may be at the beginning of a steep upward trend in surface temperatures, without an easy going back. The Hadley Centre models show us that a general temperature rise over the Amazon Basin of 4o C would put paid to much of the humid tropical rainforests.

And, remember that the 0.7o C rise in temperature from pre-industrial times, most of it since World War 2, is already the cause of considerable havoc. The heat-waves in Europe during the summer of 2004, the hurricane that struck the southern coast of Brazil, the tropical storm that reached as far north as Spain during 2005, are worrying indications that global warming does not lead to linear changes but to abrupt, even unforeseen ones.

Global warming is also causing fundamental problems in agriculture, especially where it matters. According to the UN's Food and Agricultural Organization (FAO), global grain production per person in 2002, fell to its lowest level since 1970 and we have now had a spate of years in which the global grain harvest has fallen below demand, in the United States the shortfall being made up from stocks held in private and government stores. If relatively small fluctuations in climate can have a major effect on cereal crop production that does not bode well for a world population that is not only increasing but is increasing its demands for more and more animal protein, much of which is produced through feeding grains, such as maize and supplemented with protein from soya, the latter increasingly derived from Brazil's Amazonia
.

As climate is essentially an emergent property of life's interaction with its immediate environment, we surely cannot accept uncritically those climate GCMs that treat life as little more than a black box that functions as an established unvarying constant irrespective of climatic events and the temperature changes that may be taking place around it. Based on such models, the IPCC's predictions are deficient at best; they may indeed be dangerously misleading in making us think we have more time than we actually have.

We must therefore applaud institutes of climatology that have heralded the way to incorporate a dynamic terrestrial carbon cycle into their climate models. That relationship goes both ways: climate has its impact on vegetation, for instance through changes in temperature and rainfall, and changes to vegetation then feed back on the processes that bring about climate change, such as by increasing levels of carbon dioxide in the atmosphere from the decomposition of biomass within soils and by altering the water budget and therefore the amount of latent heat from water vapour in the atmosphere.

Peter Cox, who has the UK Met Office Chair in Climate System Dynamics at the University of Exeter, as well as Richard Betts and his colleagues at the UK Meteorological Office, are now advancing climate models that make a valid attempt to incorporate relevant living processes, as expressed through biomass production and decay, in different ecosystems. Their shock results indicate that a 'business-as-usual' trend in greenhouse gas accumulations in the atmosphere may lead to a sharp transition from a world in which primary photosynthetic production is enhanced and encouraged to one in which decomposition, especially from soils, takes over, undermining the accumulation of biomass of the previous 200 years and probably much longer.

Before the end of this century, if the models are anywhere near correct, then instead of soils, terrestrial vegetation and the oceans accumulating more than an atmosphere's worth of carbon, namely 1000 gigatonnes, and keeping all that potential carbon dioxide out of the atmosphere, we may, on the contrary, have to face the consequences of an atmosphere with more than 600 gigatonnes of carbon over and above current levels.

That so, without taking any account of current and future emissions, we will experience a nigh on doubling of the current atmospheric levels of greenhouse gases – a momentous change in the span of a few years. Conceivably atmospheric concentrations of greenhouse gases could rise to four times pre-industrial levels – a state of affairs not seen for millions of years.

There are ifs and buts about any climate models, no less so the Hadley Centre models, nevertheless we must take their predictions seriously, especially their prognosis of a world considerably warmer than that indicated in the models used by the IPCC in its Fourth Assessment Report of 2007. The Hadley Centre talks of surface terrestrial temperatures reaching on average nearly 9o C above those that prevailed at the end of the eighteenth century.

Of course, there is much we do not understand, such as the role that clouds are likely to play in a warmer world. James Lovelock, the author of the Gaia Theory, has suggested that even though the atmosphere over the oceans may contain greater humidity because of warmer temperatures, cloud formation, especially of marine stratus clouds, may actually diminish. The reason, he suggests, is because of a likely sharp decline in the populations of coccolithophore-like algae. It is those algae that produce dimethylsulphide which, on oxidation to sulphur dioxide, generates cloud condensation nuclei.

If Lovelock is right and marine clouds are primarily generated because of cloud condensation nuclei from living organisms, then a warmer clime, through the spread of nutrient deficient zones of the oceans, will lead to a decline in phytoplankton, a reduction in marine stratus clouds and therefore more warming through the oceans absorbing light. In addition, if clouds do form, they are likely to be higher clouds on account of a warmer lower atmosphere and therefore paradoxically cooler clouds. Such clouds radiate less heat back into space and the overall result will be a warming of the Earth's surface rather than a cooling.

The Amazon as a climate system

The Amazon Basin, is a remarkable climatic system that has emerged from a tight association of air mass movements and forest-driven evapotranspiration. In effect, the humid tropical rainforests of the Basin constantly recharge the air flowing above the canopy with water vapour, the net result being that several million square kilometres of forest receive sufficient rainfall for their survival.

In addition, just as the coccolithophores release cloud forming substances over the fertile parts of the ocean, as in the North Atlantic, so too the tropical humid forests of the Amazon release terpenes and isoprenes that, on oxidation, form cloud condensation nuclei. Without such a vapour-cloud regenerating system, those rich forests far to the west of the Basin would in all probability vanish.

The water-transporting mass circulation system of the Hadley Cell begins in the tropical Atlantic Ocean, off the coast of Africa, where dry, sinking air travels westwards either side of the equator towards the Brazilian coastline, picking up more and more moisture as it goes. Those Trade Winds, *vientos alisios*, from the two hemispheres converge at the solar equator and finish up moving virtually as one body over the Atlantic forests of Brazil. Through a process known as 'convection' they then form giant cumulo-nimbus thunder clouds that may stretch for several hundred kilometres at a time.

By measuring the change in the ratio of oxygen isotopes — the less common isotope, oxygen-18 being one-eighth heavier than the common oxygen-16 — as water was first evaporated from the ocean and then precipitated as rain, Eneas Salati, a Brazilian physicist discovered that the proportion of the heavier oxygen-18 did not reduce as rapidly as one would have predicted in the rains that fell further to the west, indicating therefore that a process of atmospheric recharging was taking place. That could only mean that clouds over the Amazon Basin had formed from evaporated rain arising from a previous downpour, thus putting back a greater proportion of the heavy isotope of oxygen into the atmosphere, from where it would again preferentially precipitate.

Salati's work has since been confirmed and extended. In effect, the process of downpour and then recharging takes place as much as six times as the air-mass moves over the Basin, from the Atlantic Ocean and all the way to the Andes. Furthermore, as much as three-quarters of the total volume of water that was originally picked up by the trade winds from the Atlantic Ocean, gets pumped back into the atmosphere, finally leaving the Basin altogether in the mass air circulation that climatologists name as the Hadley Cell after the famous 18th century English astronomer. The Brazilian climatologists, Carlos Molion, Antonio Nobre, Jose Marengo and others, have evidence that as much as 50 per cent of the original rainfall gets exported out of the Basin.

Water requires considerable energy to evaporate, some 600 calories per gram; equally when it condenses and falls as rain that same energy is released as heat and fuels the further expansion of the clouds so that they rise still further, ever releasing more water as rain. Meanwhile, the spin of the Earth — the Coriolis Force — draws the Hadley Cell air mass towards the northeast in the northern hemisphere and its mirror image, hence southeast, in the southern hemisphere. As it loses its water, the air mass cools and becomes denser, sinking over East Africa as dry air. Put another way, the deserts of the Sahara and Kalahari are the other side of the coin of the wet, warm air of the Amazon. And now, with the ground-breaking work of Makarieva and Gorshkov, we have evidence of the extraordinary mechanism by which natural forests, through high rates of evapotranspiration, even during relatively short dry seasons, will drive the entire Hadley Cell circulation from the equator to the higher latitudes of the tropics and will affect the entire air mass circulation systems of the planet. The corollary, that without the natural forests across equatorial continents such as South America and Africa, global climate will change dramatically, with drastic consequences for humanity, let alone the planet as a whole, must surely worry us on a par with our concerns for the impact of our greenhouse gas emissions.

The combined process of evaporation/transpiration just over the Legal Amazon of Brazil, puts back into the atmosphere more than 6 million million (1012 or tera) tonnes of water vapour every year — equivalent in energy terms to many times more than the total currently used by all human beings for all their activities. In fact, more than three quarters of the sun's energy over the Amazon Basin is taken up in the evapo-transpiration process, and since the sun delivers some 6 million atomic bombs worth of solar energy every day over the Brazilian Amazon, we are talking big energy. Antonio Nobre, in a personal communication, informs me that 20,000 million tonnes of water are evaporated and transpired every day over the 5 million km2 of the Legal Amazon of Brazil, an amount that exceeds the 17,000 million tonne flush of water each day into the Atlantic Ocean via the Amazon River. To put that into another perspective, the energy required to bring about that evapotranspiration is equivalent to the summed output of Itaipu, the largest hydroelectric dam in the world, for a period of 135 years.

The forest, as a gigantic, irreplaceable water pump, is therefore an essential part of the Hadley mass air circulation system. And it is that system which takes energy in the form of masses of humid air out and away from the Amazon Basin to the higher latitudes, to the more temperate parts of the planet. Argentina, thousands of miles away from the Amazon Basin gets no less than half of its rain, courtesy of the rainforest, a fact that few, if any of the Argentinian landowners are aware of. And in equal ignorance, the United States receives its share of the bounty, particularly over the Midwest.

The system of forest and rainfall may appear to be rugged and therefore resistant to perturbations, but the UK Met Office's Hadley Centre finds otherwise. According to their models, global warming, if uncurbed, will result in a dramatic change in the air mass movement such that it switches from being driven across the Atlantic Ocean by the Trade Winds and hence across the Amazon Basin towards the Andes, to a more El-Niño like pattern, in which the air mass movement passes eastwards across the Pacific Ocean, then to be deflected by the Andes. The net result is a much diminished rainfall regime over the Amazon Basin and the consequences, according to the models, are forest die-back and death, given the vulnerability of the trees to drought-like conditions in successive years. In a matter of decades, decomposition over the Basin may well lead to more than 70 gigatonnes of carbon escaping as carbon dioxide into the atmosphere.

Vastness of Amazon no safeguard against deforestation

Forest destruction in the Amazon Basin is carried out, relatively speaking, by just a handful of Brazilians, and the same is true of other countries where tropical deforestation is rife, such as Indonesia or indeed other Latin American countries. In Colombia, for example, a small number compared to the total population are now destroying tropical rainforest, primarily for coca production. One of the problems there is that destruction of illicit crops and collaterally legitimate food crops through fumigation is fuelling the cancerous destruction of more forest. Coca production has actually increased in Colombia despite an ever more intensive search and destroy regime under *Plan Colombia*.

The Amazon rainforests play such a significant role in global climate and rainfall, that Brazilian climatologist Pedro Silva Dias lays claims to being able to predict rainfall in South Africa, six months after rainfall patterns over the Amazon. His work and that of Roni Avissar, at Duke University in the United States, indicate that what falls as rain over the Amazon Basin is paralleled, three to four months later, by rain falling over the US corn belt during its Spring and Summer.

Over the Brazilian Amazon evapotranspiration takes up 1.63 x 1022 joules per year of the Sun's energy, which is equivalent to nearly 520 terawatts and therefore 40 times the total energy used by humanity. A sizeable proportion of that massive amount of energy gets teleconnected and consequently the Amazon Basin is responsible for a natural and essential process of energy transfer across the planet that is equivalent to one half that now accumulated in the atmosphere on account of 150 years of anthropogenic greenhouse gas emissions. At the same time, even were there no forest, the water and energy transport would not be zero, because both are largely driven by the difference in the planetary energy balance between the equator and the poles. Nevertheless, it has become clear that the functioning of the Amazon Basin as a hydrological power engine is a critical component of contemporary climate.

Teleconnection

Teleconnection is the name given for such transfers of energy by means of rainfall to the United States, to South Africa and towards Europe from Amazonia and it comprises relatively slow-moving moist masses of air that, like a slowly moving train, push their way northwards and southwards out of the Basin, carrying their precious cargo of water in the form of water vapour. In effect, we are talking of water that is absolutely essential for the growth and survival of crops fundamental to the needs of the United States. Let the forests of the Amazon wither away, or just cut them down and burn them, as cattle ranchers and soya bean farmers are currently doing, and the US will suffer like none had ever imagined it would.

Thunderstorms are the key to teleconnection. Most thunderstorms occur in a narrow band around the equator, some 1500 to 5000 a day, rising to a considerable height as precipitating water fuels their upward motion through the release of latent energy. Perhaps as much as two-thirds of precipitation around the planet is affected by the formation of cumulonimbus and stratiform cloud systems generated within the tropics. Scientists now believe that the heat, moisture and kinetic energy, which get carried from the tropics to the middle and higher latitudes in the mass circulation system, have a profound impact on the ridge and trough pattern associated with the polar jet stream.

Changes in land-use and in land cover over the humid tropics are therefore affecting climate simply by altering and transforming the dynamics of cloud formation. As Professor Roger Pielke of Colorado State University, points out: "These alterations in cumulus convection are teleconnected to middle and higher latitudes, which alters the weather in those regions. This effect appears to be most clearly defined in the Winter Hemisphere."

Roni Avissar and Pedro Silva Dias point out that *teleconnection* processes between Amazonia and the United States depend on the humid tropical forests remaining largely intact over the Basin's 7 million square kilometres.

The other issue relates to the current frenzied destruction of the rainforest and its potential impact on climate. Thunderstorms are the key to the survival of the forest because they bring essential rain, in some parts of the Amazon, as in Colombia, to the tune of 5 or more metres a year. Cut the forest down and rainfall dwindles. That causes still more of the forest to die, so reducing rainfall still further and bringing about a vicious cycle of spreading degradation as fires begin to rage out of control.

During the drought of 1988, caused by a powerful El Niño event in the tropical Pacific, when the normal oceanic currents were overturned, the United States had a foretaste of what would happen were the Amazonian forests to disappear. Corn yields fell by more than a quarter, swallowing up the surpluses of previous years, and for the first time leaving production behind US consumption. The federal government was forced to pay out three billion dollars as debt relief to farmers.

To date climatologists have assumed that the amount of rainfall is dependent on the amount of forest and that as more and more of the forest goes, so rainfall will decline proportionately. By using a higher resolution 'mesoscale' modelling – in other words focussing on a limited region, in this instance Rondonia, Roni Avissar and Pedro Silva Dias have uncovered a very different picture, with rainfall actually increasing when clearings are not too big, but then after a critical point, dwindling away rapidly and causing the remaining forest to crash.

When a clearing is no more than a certain size, probably no more than a few kilometres across, and if the forest around is relatively intact, then the mass of warm air that rises over the clearing, will suck in cooler, more humid, air from the surrounding forest. That convection process leads to the formation of thunderstorms. Under those circumstances rainfall will increase, perhaps by as much as 10 per cent. On the other hand, make the clearing relatively large, when the forest is no longer large enough or close enough to moisten the updraft of air, and the convection process literally runs out of steam. Rainfall then declines sharply.

One effect of drying out is to make the forest increasingly vulnerable to fire, especially during dry years, such as are associated with strong El Niños, like that of 1998, when vast areas of the state of Roraima were ablaze.

Deforestation and fires

Then, as Bill Laurance puts it, "fires lit by small-scale farmers swept through an estimated 3.4 million hectares of fragmented and natural forest, savanna, regrowth and farmlands in the northern Amazonian state of Roraima. Even in the absence of drought", he continues, "Amazon forest remnants experience sharply elevated rates of tree mortality and damage, apparently as a result of increased desiccation and wind turbulence near forest edges. These changes lead to a substantial loss of forest biomass, which has been estimated to produce from 3 to 16 million tonnes of carbon emissions per year in the Brazilian Amazon alone. In drought years, the negative effects of fragmentation may well increase."

Thunderstorms and lightning strikes have been blamed for starting fires. Yet, according to Mark Cochrane, South Dakota State University Michigan State University and Daniel Nepstad, of the Woods Hole Research Center, the chances of fires taking hold in the natural forest as a result of lightning are minimal. Fires in the Amazon are a consequence of deforestation and land-use change. Indeed, Nepstad and his colleagues find that forests that have been subjected at least once to fires are far more vulnerable to successive fires in terms of tree mortality. Initial fires may cause up to 45 per cent mortality in trees over 20 dbh (diameter breast height) and subsequent fires up to 98 per cent mortality. Meanwhile, during observations of fires in December 1997 fires in the eastern part of the Amazon, in Tailândia, they found that initial fires led to the immediate release of 15 tonnes of carbon per hectare and recurrent burns, up to 140 tonnes of carbon per hectare.

Charcoal studies indicate that in lowland tropical rainforests natural fires are rare events, perhaps involving a rotation of hundreds if not thousands of years. According to recent research by Cochrane and Laurance, "Fire-return intervals of less than 90 years can eliminate rain forest tree species, whereas intervals of less than 20 years may eradicate trees entirely... Fragmented forests in the eastern Amazon are currently experiencing fire rotations of between 7 and 14 years. Previously burned forests are even more prone to burning, with calculated fire rotations of less than 5 years."

Successive dry years, such as a succession of El Niño years, will also make the forest extremely vulnerable to drying-out and fires. During the exceedingly strong El Niño of 1998, says Nepstad, one third of Brazil's Amazon rainforest experienced the soil drying out down to 5 metres, close to the limits of water-uptake through the roots. Consequently 3.5 million square kilometres were at risk, with some trees having to pull water up from as deep as 8 metres. During that period of stress, Nepstad noted that tree growth went down practically to zero as evidenced by canopy thinning rather than leaf-shedding.

How close are we to that critical point when the forests are no longer big enough to sustain their humidity and that of the surrounding air? It may be that we are perilously close in some regions of the Brazilian Amazon, such as in the southwest, on the border between Brazil and Bolivia, where rainfall has recently begun to increase. To some that may indicate that deforestation is not linked to rainfall: to Roni Avissar, such increases spell potential disaster and the remaining forest may be in grave danger of collapsing on account of an impending dramatic decline in rainfall.

Lucy Hutrya and Steven Wofsy at Harvard have recently discovered that rainfall is declining in a stretch between Tocantins and Guyana as a result of deforestation encompassing some 11 per cent of the region. That decline indicates that the models of the Amazon rainforests playing a vital role in the hydrology of the Basin are essentially and worryingly correct. In addition, a study of the role of rainforests in keeping the air charged with water vapour over Costa Rica indicates that deforestation is leading to significant reductions in rainfall over the mountains, thus affecting the montane ecology of the region. Changes in hydrology as a result of deforestation within the Amazon Basin will have a massive impact on rainfall patterns over the tropical Andes.

In fact, the rapid loss of glaciers in the Colombian Andes is in large measure caused by precipitation changes from deforestation and soils consequently drying out, rather than from global warming *per se*. Furthermore, once glaciers start retreating they expose a darker rocky surface, which has a lower albedo than ice and snow. The absorbed energy from the Sun therefore warms up the area faster, leading to accelerated melting. In fact, considerably more precipitation is required over the tropical Andes, in order to maintain glaciation than is the case at higher latitudes. The reason is that the tropical Andes receive two or more times the short wave radiation from the Sun compared with the Earth's extremities.

World-granary countries such as the United States are threatened on both counts. First, when the Amazon self-destructs through being sucked dry by agro-industry. Second, because the accumulating impact of greenhouse gases in the atmosphere may lead within a few decades to a sudden switch in air mass movements over the Pacific and the Americas. Those El Niño-like changes will combine with the impact of massive agro-industrial clearings to the point when the humid rainforests of the Amazon can no longer sustain themselves. A climate disaster if ever there was one and certainly on the scale of cinema's *The Day after Tomorrow.*

Rainfall and deforestation

A change in climate that led to less rainfall against higher temperatures and elevated atmospheric carbon dioxide would likely put paid to the forest. Powerful positive feedbacks, leading to successive forest die-back would be set in train. Conventional wisdom has it that the forest largely disappeared during the last glacial maximum because of colder temperatures and reduced precipitation. The fragmented forest that survived because of local, still suitable conditions, as in the northwest of the Basin, retained a rich biodiversity that, with the rapid warming that followed the end of the ice-age, provided the seed for reforesting the region around. Hence the notion of biological refugia providing the basis for today's extraordinary biodiversity.

Such a notion has been turned on its head through careful analysis of the sediment carried out from the Amazon into the Atlantic and covering the continental shelf. The evidence for the forest disappearing except for pockets of refugia does not stand up. On the contrary, according to the work of Sharon Cowling and Mark Maslin, among others, the forest survived, although undoubtedly with a substantially different structure from that found today. Certainly, with the colder, more arid conditions that generally prevailed, montane forest from the Andes was able to invade some parts of the Basin.

Now Cowling, Maslin and Martin Sykes have modelled the impact of each one of the three physiological criteria of atmospheric carbon dioxide concentration, rainfall levels and temperature on the mean leaf area index, which is basically a measure of leaf coverage and hence whether the vegetation is forest with a closed canopy or is more savannah-like. The modelling reinforces strongly the palaeontological data taken from the mouth of the Amazon. It shows that forest can withstand low carbon dioxide levels and lower rainfall only when temperatures are also lower compared with the modern conditions of today.

The main effect of the cooler temperatures is to reduce the photosynthetic losses brought about by photorespiration in which oxygen competes with carbon dioxide for Rubisco, the carbon-fixing enzyme in C3 plants. In addition lower temperatures reduce evapotranspiration with the result that vegetation can make better use of the water available for carbon uptake into the leaves. As Sharon Cowling and her colleagues point out, "Cooler LGM (Last Glacial Maximum) temperatures may have helped to improve carbon and water balance in glacial-age tropical forests, thereby allowing them to out-compete grasslands and maintain dominance within most of the Amazon Basin."

As Antonio Nobre points out, the relative lack of large natural herbivores in Amazonia, in comparison to Africa, with its large areas of savannah, suggests that the forests of the Basin have remained intact even over past ice ages. Moreover, if the forests had indeed vanished from large areas of the Basin, then their recovery may never have happened, given the essential role that evapotranspiration plays in watering forests in the central and western part of the region.

But what of the future if temperatures rise over the forest and rainfall decreases? The higher carbon dioxide levels of modern times will certainly offset some of the photorespiration losses that will arise from higher temperatures, but the evidence is that the forest will suffer irremediably from the hotter internal conditions brought about through diminished availability of water for transpiration. The canopy-thinning that Nepstad noted during severe El Niño episodes indicates that, physiologically, the humid rainforests of the Amazon are close to their tolerance levels. They are now living close to the edge; hence warmer temperatures and less precipitation are likely to serve as their coup de grâce.

Rossby wave teleconnection at risk from deforestation

Nicola Gedney and Paul Valdes, from the Department of Meteorology, University of Reading, and Bristol University show from their models that, independent of global warming, deforestation of the Amazon would lead to considerable disturbances to climate over the north east Atlantic and western Europe as well as the eastern seaboard of the United States, especially during the northern hemisphere winter months, which would consequently become considerably wetter.

Normally, during those winter months, convection is at its strongest over the Amazon Basin. Such convection, based on the lifting of considerable quantities of vapour, then propagates strong Rossby waves some of which head out in a north-westerly direction across the Atlantic towards West Europe. The Rossby waves emanating from the Amazon tend to be suppressed by strong easterlies aloft; nevertheless, under normal circumstances, with the forest intact, the latent heat source for the Rossby waves is strong enough to override the easterlies. That situation reverses when the forest is replaced by grassland, because of a reduced precipitation over the Basin, which itself leads to a generalised weakening of the tropical air mass circulation - the Walker and Hadley cells. Under those circumstances the easterlies aloft bring about a suppression of the now weakened Rossby waves.

As Gedney and Valdes point out: "Our results strongly suggest that there is a relatively direct physical link between changes over the deforested region and the climate of the North Atlantic and western Europe. Changes in Amazonian land cover result in less heating of the atmosphere above. This then weakens the local Hadley Circulation resulting in reduced descent and increased rainfall over the south eastern US. The result of this is a modification to the Rossby wave source which causes subsequent changes in the circulation at mid and high latitudes in the northern hemisphere winter. This in turn causes changes in precipitation, namely an increase over the North Atlantic and a suggestion of some change over Western Europe."

Deforestation and rising temperatures

Many studies have shown the sharp differences in daily temperature between a natural forest and cleared land. In Nigeria, for example, the day-time temperature just above the soil in a clearing was 5° C higher than in the nearby forest and humidity was 49 per cent compared to the forest's 87 per cent. Clearings are also far more likely to flood and consequently erode. Carlos Molion, at the State University in Alagoas, points out that the forest canopy in the Amazon intercepts on average about 15 per cent of the rainfall, a large proportion of which then evaporates directly back into the atmosphere. The removal of the canopy leads to as much as 4000 tonnes of water per hectare hitting the ground, causing selective erosion of finer clay particles and leaving behind increasingly coarse sand. Soil under intact forest absorbs ten times more water compared with pasture, where erosion rates may be 1000 times greater.

In conclusion, it is becoming increasingly clear that we perturb climate, not simply because of greenhouse gas emissions from fossil fuel burning, but also because ecosystems such as those of the Amazon Basin play a massive role in the transport of energy from the equator to the more temperate regions of the planet. Our climate system, with its particular prevailing weather patterns, needs those energy transfers.

Consequently, we must do all in our power to prevent agro-industrial enterprises, whether for soyabean or cattle production, from destroying anymore of the Amazonian tropical rainforests.

At the same time as putting all our energies into preventing massive tropical forest destruction, we must be aware that humid tropical rainforests everywhere will be threatened by global warming bringing about a drastic switch in ocean currents and air mass movements. It is a tall order, but one that we must urgently address, simultaneously to do all in our powers to conserve tropical rainforests, and worldwide to reduce greenhouse gas emissions. And should we prove unable to curb our greenhouse gas emissions, it may be that the forests of Amazonia are anyway doomed.

Conservationists must take these issues on board, because if they fail to take the relationship between Amazonian forests and climate into account, then all those worthy projects in which they have managed to conserve isolated patches of forest, connected through ecological corridors, will be as dust. From Avissar's work, we may well need at least 60 per cent of the humid tropical rainforest intact – certainly no less.

But is any government going to forgo the quick returns on exploiting the natural resources of an area as large as the Amazon? As Bill Laurance, Philip Fearnside and Brazilian environmentalists point out, one way of persuading governments to leave well alone would be through a carbon credit system that realised the value of *avoided* deforestation, rather than just a value for new forest projects. The first commitment period of the Kyoto Protocol, largely because of vigorous campaigning by environmentalists against the notion of credits for existing forests, will allow credits only for land-use change when that leads to verifiable carbon uptake. Maybe, by the second commitment period of the Kyoto Protocol, post 2010, those campaigners, as well as governments, will have realised just how essential it is to find ways to avoid deforestation if the aim is to stabilise climate.

Kyoto Protocol misses the point

Indeed, the problem with the Kyoto Protocol is that while *Article 2* establishes that developed countries should 'protect and enhance sinks and reserves, promote sustainable forest management practices, aforestation and reforestation', *Article 12* ensures that existing forests are not included. The Protocol therefore reflects the wishes of environmentalists, and in particular those of western Europe and the United States, who have been strongly opposed to the notion that CDMs include *avoided deforestation* on the understandable grounds that the carbon is already contained in the forest and soil.

Such environmentalists were justifiably worried that industrialised countries such as the US would wriggle out of their responsibilities to cut greenhouse gas emissions through claims that the existence and expansion of natural forests within state boundaries were doing the job for them. Hence, the environmentalists have argued that if *avoided deforestation* were to be legitimised in the CDMs, those countries (and companies) benefiting from any carbon trading on forest conservation would need to do little more than look around for the cheapest carbon offsets and count those against their own emissions.

To date the Brazilian government has also expressed its opposition to the inclusion of forest conservation and its corollary, a reduction in the rate of deforestation, as being legitimate opportunities for CDMs. Clearly the Brazilian government has believed that it will gain more through inviting in external investment in exploiting the land beneath the forests than it ever would through gaining carbon credits. That view is valid only if the true ecological and climatological services of the Amazon Basin are ignored.

The issue is not simply one of biodiversity. The relationship between tropical forests and climate must be our first consideration when justifying the need for conservation. Biodiversity conservation then falls naturally in place as the means by which a tropical forest can maintain itself. The means to ensure the conservation of the remaining tropical forests and the rehabilitation of those that have recently been destroyed is therefore a priority and one that should have equal status as concerns over the emissions of greenhouse gases in the deliberations and recommended actions from bodies such as the Intergovernmental Panel on Climate Change (IPCC).

It is therefore a matter of urgency that we value the rainforest primarily for its ecological and climatological services and for that reason a mechanism, such as CDM, must be developed that recognises that the value of the forest as a natural carbon sink is only one side of the vital role that the forest plays in determining climate processes while sustaining itself.

Despite all the concern about the future of the Amazon, an international process that values the forest as a natural carbon sink and for its climate services has yet to be developed. Fortunately Amazon countries are beginning to realise that the further loss of this vast moisture reserve could cause great damage to farming across much of South America. Let us trust that those concerns will become a priority in the decision-making of all countries in the world, whether with or without tropical forests, in the process of preventing irremediable climate change: in addition, that countries specifically with vast expanses of humid tropical forests will take the initiative in getting global agreements in place that will result in protection of those same forests. Obviously, processes of compensation for maintaining the essential ecological services of such forests will need to be thrashed out.

SOURCES

Barrett, Peter J. 1996. Antarctic Palaeoenvironment through Cenozoic Times. *Terra Antarctica* , Vol. 3. No. 2, pp. 103-119

Barrett, Peter. 2003. Cooling a continent. *Nature* , Vol. 421, 16 January, pp. 221-222.

Betts, Richard A., Cox, Peter M., Collins, Matthew, Gash, John H.C., Harris, Philip P., Huntingford, Chris, Jones, Chris D. and Williams Keith D. *Amazonian forest die-back in the Hadley Centre coupled climate-vegetation model* . UK Met Office, Hadley Centre, 2002.

Cochrane, Mark A., Ane Alencar, Mark D. Schulze, Carlos M. Souza Jr., Daniel C. Nepstad, Paul Lefebvre, and Eric A. Davidson. Positive Feedbacks in the Fire Dynamic of Closed Canopy Tropical Forests. *Science* , **284** , 1832-1835, 11 June, 1999.

Cox, Peter M., Richard A. Betts, Chris Jones, Steven A. Spall and Ian J. Totterdell. Acceleration of global-warming due to carbon-cycle feedbacks in a coupled climate model. *Nature, Letters* , **408** , Nov 9, 2000.

Fearnside, Philip M. Greenhouse Gases from Deforestation in Brazilian Amazonia: Net Committed Emissions. *Climatic Change* , **35** , (3) 321-360, 1997.

Fearnside, Philip. M. Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. *Climatic Change* **46**, 115-158, 2000.

Gedney, Nicola, and Paul J. Valdes. 2000. The Effect of Amazonian deforestation on the northern hemisphere circulation and climate. *Geophysical Research Letters,* **19,** 3053-3056 **.**

Grace, John. Forests and the Global Carbon Cycle. *S.It.E. Atti,* **17** , 7-11, 1996.
Hutrya, Lucy., and Wofsy, Steven. *Geophysical Research Letters*. www.agu.org/pubs/crossref/2005/2005GL024981.shtml

Laurence, W.F., M.A. Cochrane, S. Bergen, P.M. Fearnside, P. Delamonica, C. Barber, S. D'Angelo, T. Fernandes, 2001. The Future of the Brazilian Amazon, *Science*, Vol 291. Issue 5503, 438-439.

Makariaieva, A.M., V.G.Gorshkov. 2006. Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. *Hydrol. Earth Sys. Sci. Discuss.,* 3. 2621-2673.

Pielke, R. A. 2002. Mesoscale meteorological modeling, 2nd edition. San Diego: Academic Press.

Salati, E., 1987. The Forest and the Hydrological Cycle. In *The Geophysiology of Amazonia* , R. E. Dickinson, ed. New York: Wiley Interscience.

Silva Dias P., and R. Avissar, 2002. *The Future of the Amazon: Impacts of Deforestation and Climate* . Conference, unpublished proceedings. Smithsonian Tropical Research Institute, Panama.

Silva Dias, M. A. F., W. Petersen, P. Silva Dias, A. K. Betts, A. M. Gomes, G. F. Fisch, M. A. Lima, M. Longo, M. A. Antonio, 2002. A case study of the process of organization of convection into precipitating convective lines in southwest Amazon. *Journal of Geophysical Research,* **107** .

Ray, Deepak K. et al. Impact of land use on Costa Rican tropical montane cloud forests: Sensitivity of orographic cloud formation to deforestation in the plains. *Journal of Geophysical Research*, **111**, 2006.

Sioli, Harald. The Effects of Deforestation in Amazonia. *The Ecologist,* **17**, No.4/5, 1987.

Werth, D. and R. Avissar, 2002. The effects of deforestation in Amazonia on the climate of other regions. *Journal of Geophysical. Res.,* 2002.